LITTLE BLUE BOOK NO. 486
Edited by E. Haldeman-Julius

Hints on Soils and Fertilizers

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HALDEMAN-JULIUS COMPANY
GIRARD, KANSAS

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THE NATURE OF SOIL

In delving into the mysteries of the soil, it is not without appreciation of the fact that proper handling of the soil is still very little understood by those who come in closest contact with it. Despite the long period of time that has elapsed since man first inhabited this earth, and has constantly lived off the fruits of the earth since that time, comparatively slow progress has been made in wresting from Mother Nature the secrets that she has locked up in the earth's crust. Nearly everybody knows that if a seed is planted in the soil, the seed will sprout, and eventually grow into a mature plant, if the environment is favorable. But just how does that seed take its food from the soil and grow into a fine plant? It is certain that the small seed does not have enough plant food in itself to produce food enough for the seed to grow into a large plant. No, the seed must soon turn to the soil for its existence, and the manner by which this seed takes this food from the soil, and numerous other processes peculiar to the characteristics of the soil, will be explained in this booklet. It might well be added at this time, that many results of the workings of the soil are known to those who till the soil, but very few know just why these results obtain, or what to expect when a different method is employed from that ordinarily used. We will treat of the various

practices used in different parts of the country, and try to present in these pages an explanation of different soil phenomena that occur under varying conditions, in a manner that will be clear to anyone capable of reading.

Before proceeding further, we may well ask, "what is soil"? Ordinarily, we think of soil being the upper six or eight inches of the earth's crust that is used for growing crops. Now that we have our soil located, might we not inquire further as to what we really mean when we refer to the soil. Of what is soil composed? True, soil is not composed of exactly the same ingredients and exactly the same amounts in all cases, but we will first consider its general composition.

The real soil is made up of two chief ingredients, namely, humus and mineral matter. By humus, we mean decayed, or rather, partially decayed organic matter, such as barnyard manure, or a crop plowed, or turned under, such as rye, for instance. This matter of humus will be discussed more in detail in a later chapter, so we will not dwell further on this subject here. The other part of the soil is termed mineral matter, or mineral elements. These elements concern the richness of the soil, or its ability to yield a crop.

Possibly the next question that arises is concerning the origin of the soil, especially the mineral elements. There are various agencies that aid in soil formation, but all of these agencies work on one substance—rock. A rock may be defined as an aggregate of mineral elements. When certain natural forces work

on these rocks, they are slowly, gradually, but nevertheless surely, broken up into fine particles which go to make up the soil. Sudden changes of temperature, such as heat or cold, cause rocks to split and crack. Frost has a similar effect, when water freezes in small rock crevices, the expansion of water into ice causing the rocks to break into smaller pieces. Water also aids in soil formation, as it not only dissolves soil particles that are small enough, but it also has a wearing effect on rocks, as it constantly flows past a rock particle. Wind is another agency that does its part in crumbling the giant rock. Sharp particles of soil, such as sand, for instance, by being blown against rocks, tend to wear off gradually the surface of the rocks thus exposed. Certain gases, such as oxygen and carbon dioxide, also have their effect upon the rocks, largely through chemical changes. Thus it can be seen that soil formation is not a quick process, but that it has taken millions of years to bring this disintegration about, and that soil is constantly being formed, and will continue to be formed for a long time yet.

Not all soils found at a certain place were necessarily made from the rock that lies underneath it. Water, wind and ice all contribute to the transporting of soil particles, after they are small enough to be carried by these agencies, and deposit them on other rocks. We are all familiar with the running streams of water that carry small particles of soil in solution. These soil particles are not all carried a very great distance, unless extremely

fine. The coarser particles, being heavier, are soon deposited at some point further down the stream. A great number of years ago, scientists tell us (and they have sufficient proofs to verify their claims) that a huge glacier moved along this country from the north, and extended along the northern border of the United States. These large ice sheets not only leveled the topography of our land, but they dragged along a great amount of soil from the north, and deposited it hundreds of miles south of its original position. Hence, we find many locations where the top soil is of different composition than the underlying subsoil.

We have already learned that the soil contains mainly two classes of materials, humus and mineral elements. We have defined humus as decayed vegetable matter, such as the remains of plants that were not used by man, but left upon the soil. The elements of a mineral nature are just as essential to the welfare of the plant as the organic matter, or humus. We will discuss these mineral elements from a chemical point of view in our next chapter, but we will now consider them briefly from a physical standpoint.

When speaking of a soil, in general, we usually refer to it as either a sandy soil, a silt soil, as a clay soil, or as a loam of one of these soils. Now, just what do we mean when we say a soil is a sandy soil, or sandy loam, etc.? This classification is based upon the size of the soil particles that compose the soil. The sand particles are the largest classification of

soil particles that we have. These sand particles are further divided into large sand particles, medium sand, and fine sand. Not only are these sand particles the largest, but they are also the heaviest. They are the first to settle when carried by a stream of water. These sand particles are not only easily recognized by the eye, but have a rough feeling when rubbed between the fingers.

The silt particles are smaller than the sand particles. We might classify them as medium soil grains, smaller than the sand particles, but larger than the minute clay particles. These soil grains, when rubbed between the fingers, have a velvety feeling.

The smallest sized particles of soil with which we have to deal, are the clay particles. These soil grains are even smaller than the silt particles, and many times smaller than the sand particles. Anyone familiar with clayey soils knows their sticky character when moist. This is because of the amount of moisture that is retained between the minute clay particles. These small particles retain water for a longer period of time than other soils because of the fact that there are so many tiny spaces between the small particles of soil, each of which holds a minute quantity of moisture.

We thus see that the above mentioned soils are classified in this manner solely from a basis of size of soil particles. We often hear a soil referred to as a silt loam, a sandy loam, etc. This merely means that the soil referred to is not all sand, or not all silt, etc., but that it con-

tains a certain amount of the other sized soil grains, also. For instance, to use a specific example, we might classify a clay loam as a soil having 35 per cent of sand, 30 per cent silt, and 35 per cent of clay particles. In fact, it would be hard indeed to find a soil that had one hundred per cent of the same sized particles in it.

We must not leave this topic without understanding that there are various other things that go to compose the soil besides the humus and mineral elements already mentioned. There are countless soil organisms existing in the soil, which, in most cases, work for the good of the soil. Such organisms are known as worms, bacteria, and fungi. Worms usually aid in making the soil porous, so that air can penetrate the soil. The bacteria that are present in the soil are a great help in breaking down the organic matter, or humus, and decomposing it so that the plant food contained therein may be restored to the soil. Most bacteria aid in the manner just described, but there are some kinds of bacteria which are harmful to ideal soil conditions. Fortunately, these bacteria are comparatively few, and cease to be a detriment when the soil is properly cared for.

Air is another factor that must be counted on in a good soil. Strange to say, the roots of plants need air, to a certain extent, just as we need air to live. If there were no air between the soil grains that we have just been discussing, the roots of the plants could not survive. Therefore, we must make allowance for a certain amount of air in the soil, and this is

usually provided, unless the soil is so full of water that the air is crowded out.

Water, to a certain extent, is an absolute requirement for plant growth, and is usually found in the soil to some extent, at least. The form of water that the plant uses for growth is not the form that we ordinarily understand water to be. What we really mean here, is moisture, in a form that surrounds the soil grains.

Finally, we usually find more or less inorganic substances in the soil, such as the chemist would classify as "salts." These are found in greater amounts in dry climates than in wet, as the more frequent rains of the moist climates tend to wash or bleach these salts from the soil.

CHEMICAL COMPOSITION OF SOILS

We have now learned that soil, as we ordinarily understand the term, is composed of humus and mineral elements, chiefly. Now we may well ask "What are these materials composed of?" The mineral matter is obviously composed of minerals. There are a few mineral elements contained in the decaying organic matter also. Hence, we have considerable mineral elements contained in the ordinary soil. There are ten elements that are absolutely required to produce plant growth, but a few of these are gases, rather than mineral elements. These ten elements are as follows: carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulphur, calcium, iron and

magnesium. Such elements as carbon, hydrogen, oxygen and nitrogen are commonly found as gases, but they are also found as part of the solid soil particles. In fact, it is very seldom that an element is found in the pure state, but most generally in combination with one or more other elements. For instance, the mineral elements are usually found in nature as oxides, or in combination with oxygen.

Plants do not draw upon each of the above named elements in the same proportion for their plant food, and furthermore, hardly any two different kinds of plants, or crops, use the same proportion of plant food in maturing to a farm crop. For instance, an ordinary yield of cotton will remove in one season about 33 pounds of nitrogen, 6 pounds of phosphorus, and 12 pounds of potassium from one acre, while a corn crop will remove from one acre, in one season, about 95 pounds of nitrogen, 16 pounds of phosphorus, and 56 pounds of potassium. Thus, it will be seen that two different crops can vary considerably in the amount of plant food drawn from the same acreage of soil.

Three other mineral elements are found in plants, namely, sodium, silicon and aluminum, but it has been proved that these elements are not absolutely required by the plants, and all the farm crops have been grown in soils depleted of these elements, with results just as satisfactory as when these elements were present.

There are three elements, possibly four, that are used in larger quantities than are the other

elements. These elements are nitrogen, phosphorus, potassium and, in many cases, calcium. In fact, when commercial fertilizers are sold, they are sold on the basis of the first three named elements; nitrogen, phosphorus and potassium. Consequently, these are the elements that are provided most by the farmer who is interested in keeping up the fertility of his land.

The nitrogen is used by the plants in the manufacturing of protein, a form of food relished by all animals. Phosphorus is used by the plant largely in filling out the grain or fruit of the plant. Obviously, the greatest need for this element is during the later stages of plant growth. Potassium is used largely for protein and starch formation by the plants. This element is especially desirable in the growing of root crops, such as potatoes, beets, etc., which contain a high percentage of starch. Calcium (or "lime") is regarded as being essential for leaf and stalk growth. It has a double function, however, in that it sweetens the soil, or neutralizes it, so that bacteria that are beneficial to the soil can exist, as it is a well-known fact that certain crops cannot thrive on acid, or "sour" soils.

The nitrogen that is used by the plant is not in the form of the gas that is so abundant in the air. While it is true that carbon and oxygen can be taken in by the plant as a gas in the form of carbon dioxide, a gas, the plant is unable to take in the free nitrogen from the air, but must take it in through the roots of the plant, in a soluble form. Because of this fact,

nitrogen is not as plentiful a plant food as it would be if it were able to be taken in by the plant as the other gases are assimilated by it.

Phosphorus is a mineral element, and also has to be taken in through the roots of the plant. There is considerably more phosphorus removed by the ordinary farm crops annually than is put back into the soil, even when the best of care is taken to restore the plant food to the soil. As a result, many farms are not producing as large a yield as they produced formerly, because of the depletion of the phosphorus supply. While this factor is not the only cause of lessened production, it is one of the outstanding reasons why many farms do not produce the yield now that they once enjoyed. Of course, different sections of the country vary in the amount of phosphorus needed to maintain the soil fertility, but in the majority of cases it has been found that, outside of nitrogen, phosphorus was the most needed element.

Potassium is not drawn on quite so heavily by the plants as are nitrogen and phosphorus, but there are many instances where this element is seriously lacking in the soil. This element is never used in its pure state (as a silver-white metal) but only in its combinations with oxygen, or oxygen and carbon, termed "potash."

One of the matters that is often most puzzling to farmers, is the failure of certain crops to grow, despite the large amount of a certain kind of fertilizer placed on the land. The probabilities are that the farmer is not applying the kind of fertilizer which the soil lacks the most.

Most of us are familiar with the old adage, "A chain is no stronger than its weakest link." Likewise, a soil is no more productive than its scarcest element. We may apply a great quantity of phosphorus and potash to our corn land, but if the land needs nitrogen to feed to the corn, then we will get about as large a corn crop as if we had not put on any phosphorus or potash. It would be the nitrogen that would be the determining factor in this case.

Often a farmer wonders why his clover does not grow normally as it should. He may even add a complete fertilizer of nitrogen, phosphorus and potash, and still not be able to note any material gain in the yield. The trouble may lie entirely in the amount of calcium, or lime, in the soil. The soil may be not only deficient in lime for feeding purposes of the plant, but the land might be so acid, due to lack of lime, or calcium, that the bacteria that are so essential for clover to grow have left the soil, and consequently the clover is unable to thrive, simply due to a lack of this soil neutralizer.

Thus we see that the soil yields up to the plant the mineral elements demanded by the plant in the process of growing. It also furnishes nitrogen in a form that is soluble in water. The water in the soil supplies the hydrogen and part of the oxygen used by the plant. In fact, water is simply a chemical combination of hydrogen and oxygen, containing two parts of the former, and one part of the oxygen. By means of its leaves, the plant takes in carbon and oxygen in another chemical com-

bination, known as carbon dioxide. This is the same gas that people exhale in breathing, and is mildly poisonous, but the plant breathes in this gas, and immediately separates the two, retaining the carbon, and releasing the oxygen.

To sum up: A plant will grow under some conditions, and will fail to grow under others. The soil is largely the determining factor as to the success or failure of a crop, and the physical and chemical condition of the soil is the point that needs the greatest emphasis. Before proceeding further in the mysteries of the soil, perhaps it would be best to first consider something about the soil in its relation to plant growth.

HOW SOILS AFFECT PLANT GROWTH

Let us first start with a seed, and get a clear idea of just what a seed is, and then we can follow the young seedling up through its growth, and learn some of the mysteries of the plant and its relation to the soil. A seed is usually defined as a young, miniature plant that is in the dormant, or resting stage, with enough plant food surrounding it to nourish it until it is capable of sending out roots to gather its own food. These seeds are usually composed, then, of two major parts; the miniature plant, sometimes called the embryo, and the plant food surrounding the embryo.

Next, let us plant this seed in the soil, and note what takes place. We will find that if the soil is fairly warm, and if a sufficient

amount of moisture and air are incorporated in the soil, the seed will commence to sprout. This simply means that the embryo is absorbing the food material surrounding it, and is sending out a root system that is working downward into the soil, and also a stalk, or stem, that is forcing itself upwards, so that the foliage that is to follow will be able to get the sunshine and air above the surface of the ground. But it is quite obvious that the small amount of plant food contained in the original seed is not sufficient to feed the young seed indefinitely. By the time that this plant food is exhausted, the young plant, or seedling, has a fine root system established of its own, so that from that time on, the plant derives its food from the soil, by means of these small slender root filaments.

We now have the young plant in a stage where it derives its food from the soil. But what if the soil is lacking in some particular plant food? Unless the soil is unusually deficient in some plant food element, the young plant will not be hindered in its growth materially, during its early growth. But as it continues to grow through the summer, if one or more elements are lacking, a decided check in its growth will be noticeable, and a poor crop will ultimately result.

Many are often puzzled as to the manner in which plants use the elements of the soil, and are thereby enabled to grow into matured plants. It is true that the plant has a feeding apparatus differing radically from that of animals. Plants do not have teeth, stomachs or

intestines. If one has occasion to examine the roots of a plant very minutely, he will discover that besides the main large roots, there are a great number of very small, hair-like, slender threads, that are attached to the larger, coarser roots. These slender filaments are the real food gatherers for the plant. They have a habit of working their way through the soil particles, and winding themselves around these soil grains. They do not "eat" these soil particles, as many suppose, but rather, they simply absorb the moisture contained on the surface of the soil grains, or "soak it up," as it is sometimes expressed. This is simply a process of osmosis, commonly known to any school boy. The moisture contained on the surface of the soil grains is largely composed of water, but this water contains a small amount of the elements that we discussed in our last chapter, *in solution*. That is the important point. Now let us see what the plant does with the solution of minerals and salts in this water. If we could trace this solution with the naked eye, after it is taken up by the fine rootlets of the plant, we would see this solution travel up toward the main roots of the plant. If the plant happened to be a root crop, such as a potato plant, this main root would be very much enlarged, especially towards the later stages of maturity. But let us continue with our "solution." The liquid solution continues its progress upwards, through the stem of the plant until it finally reaches the leaves of the plant. Now perhaps you are commencing to wonder what the plant does with all this water, and such a

comparatively small amount of plant food. This is what happens: The leaves evaporate all this surplus water, and retain only the elements that the plant needs for growth. It is amazing to learn the amount of water that is evaporated by various plants to produce just one bushel of grain. For instance, a number of corn plants, sufficient to produce one bushel of matured corn, will evaporate during one season, over one hundred and fifty barrels of water. A rather startling assertion, is it not?

Now, let us stay with the plant a little longer, and see what happens. Did you ever wonder why practically all plants have *green* leaves? As the breakfast food poet would say, "There's a reason." The plant has a reason for green foliage, or leaves. These plants all contain a substance known to the botonist as chlorophyll, or green coloring matter. Now this green coloring matter, or chlorophyll, has the ability, in the presence of sunlight, to combine the elements that present themselves in the leaves, and manufacture them into food for the plant. For instance, it takes the carbon that is breathed in by the plant in the form of carbon dioxide, it takes the oxygen from the same source, or from water, it takes hydrogen from the water, and it takes the nitrogen from the solution, as well as all the other mineral elements that enter the leaves in the water solution, throws off what it does not need, and uses the elements that it does need, making up various combinations of these elements, which go to nourish the rest of the plant. This process cannot take place unless in the presence

of sunlight, which explains why sunlight is one essential factor for plant growth. However, it is obvious that sunlight is not necessary for a seed to sprout, or to germinate, as the seed is already sprouted before it reaches the rays of the sun.

This complicated process continues from the time the young seedling reaches the upper crust of the earth until the plant finally matures. The leaves are regarded as the factory of the plant. They manufacture, by the aid of chlorophyll, the plant food from the various elements that enter the leaves. But perhaps it has not yet been made perfectly clear as to how the plant is nourished from this food that is made in the leaves. The food must be removed from the leaves, or we would have large, bulky leaves, that would be the heaviest part of the plant. This removal of plant food takes place mostly at night, by a process known as translocation. The plant food is taken up in a stronger solution of water, and carried to the other parts of the plant, so that everything is in proper balance.

From what has just been said, it can be seen that this process of manufacturing plant food could not take place to the maximum capacity of the plant, if the proper elements were not given to the leaves, and given in sufficient quantity. This problem brings us back to the fertility of the soil, once more. What if just one necessary element is lacking in the soil, so that the leaves cannot manufacture food enough to properly supply the plant with its needs? The result will be a plant retarded in growth,

just as much as that one element is lacking. In fact, the lack of just one element may be considered a measuring stick for the yield of the crop being raised. If this one element is just half enough to supply the needs of the crop, then we may consider that we will get just half a normal crop, other conditions being favorable.

Many farmers wonder as to the best way to find out what element is lacking in their soils. It is a common experience to find farmers sending samples of some unproductive piece of land to their Experiment Station, to have it analyzed, chemically, so they may discover this elusive element. But this method fails to give the farmer the information that he seeks, because, while the chemist can analyze his soil, and find out the elements contained in the soil, as well as finding the different proportions of the various elements, he cannot tell the farmer how much of each element is *available*. And this is the point over which the farmer is concerned. He doesn't care a snap if he has sixty per cent of nitrogen locked up in his soil, if he is unable to learn the amount that is available for plant food. Hence, this method is of little use to the farmer who wishes to determine the needs of his soil.

There is a method, however, that is very practical, and one which any farmer can use, although the results cannot be determined very speedily. This method is known as the test plot method. As has been stated in a previous chapter, the elements most used by plants, outside of the gaseous elements, are nitrogen, phos-

phorus, potash and, especially in the humid climates, calcium, or lime. A farmer who is anxious to find out just what elements his soil lacks, can procure a small amount of these elements, and spread them over a small plot of ground in his field, and then note the results on the crop being raised in this plot. If this material cannot be secured from some local fertilizer dealer, the farmer can probably secure this material through the county agricultural agent, or from his State agricultural college at little or no cost, especially when it is made known that it is for experimental purposes. Following is a plan of testing that has been found very convenient:

Layout of Convenient Testing Plot for Fertilizer Tests

Length of each plot=4 rods

1 rod wide	5 lb. of Nitrate of Soda	Plot 1

Blank Area, 1 rod wide, unfertilized

1 rod wide	10 lb. of Acid Phosphate	Plot 2

Blank Area, 1 rod wide, unfertilized

1 rod wide	5 lb. of Potassium Sulphate	Plot 3

Blank Area, 1 rod wide, unfertilized

1 rod wide	5 lb. of Nitrate of Soda 10 lb. of Acid Phosphate 5 lb. of Potassium Sulphate	Plot 4

Let us now examine the above plot. We find that each plot in the diagram is 4 rods long, and one rod wide, with a width of one rod between each plot on which there is no fertilizer. This blank space of one rod wide is left between each of these plots to serve as a check. By this arrangement, the results of each plot can be compared very easily to the untreated ground, or blank space. It also aids in preventing the fertilizer from one plot from getting over into the other plot, as the width of one rod is usually sufficient to overcome any defect in the distribution of the fertilizer.

In plot one, we will apply 5 pounds of nitrate of soda. This is a readily available form of nitrogen. In plot number two, we will apply ten pounds of acid phosphate, a quickly available form of the phosphorus element. Then in our third plot we will apply 5 pounds of potassium sulphate, a good source of potash. Finally. in our fourth plot, we will add the three fertilizers that were applied separately in the other three plots and apply them all in this plot, and in the same amount that they were applied in each of the other plots separately. Hence we are now in a position to note during the growing season, and especially at the maturity of the crop raised, just what element or elements are lacking in this particular piece of ground, and also an idea of how bad the element or elements are needed. It might be added at this time, that different crops do not respond alike to these tests, as we have previously noted that corn and cotton, for in-

stance, remove different proportions of the plant food elements.

In some parts of the country, lime is an important factor in crop production. In such cases, this factor can be determined in the same plot, by applying some form of commercial lime to the lower half of the plot, the entire width of the plot. Thus the liming results can be noted as well as the fertilizer needs. If the lower part of the plot produces a much more vigorous growth of plants than the upper half of the plot, it may well be concluded that lime is needed. This is especially true when some form of leguminous plant is raised, such as cow peas, soy beans, alfalfa, clover, etc.

Just one word more about how this fertilizer is to be applied. For a small plot, such as just described, it is not necessary that a fertilizer spreader be secured, although one would be very acceptable. In this case the different elements can be applied by hand. First mark off the plots, having each separate plot marked off, one rod wide, and four rods long. Then spread this by hand, being careful that this is not done on a windy day, so that none of the nitrate of soda, for instance, is blown over on to plot 2, where the acid phosphate is to be applied. It is understood, of course, that this land is already plowed, at least. Then when this is all spread, it should be immediately disced in with a disc harrow, so that it is thoroughly incorporated in the soil. Then the crop can be planted as usual. This method is being used successfully all over the country in discovering

the needs of various types of soil, and is without doubt the most practical method of determining the needs of these soils.

TILLAGE

We will next take up the matter of tillage, There is no more important process in the management of farm soils and crops than proper tillage. Proper tilth of a soil means the ease with which it can be worked. Of course, some soils are much easier to till than other soils; a sandy loam is much easier to farm than a hard, clayey soil. When we say a soil is in good tilth, we ordinarily imply that it has a crummy structure. A sandy soil does not necessarily need a large amount of organic matter to make it easily tilled, because the soil particles are of sufficient size to maintain good tilth anyway. However, a large amount of this organic matter, incorporated in the soil is very desirable, even in sandy soils, because it serves to soak up the moisture for this type of soil, which is very important during dry weather. In fact, green vegetation, one form of organic matter, when turned under, is a big help for any kind of soil, as it usually assists in improving the physical character of the soil, and is a big factor in conserving the moisture. It may be likened to a sponge, in that it soaks up the surplus water, and holds it in the soil for a much longer period than would be the case, if this organic matter were not present.

There are various reasons why soils are tilled on the farm. After a field is plowed, it is especially desirable to work up the soil into a

mellow and firm seed bed. This can be done by means of the disc harrow, the smoothing harrow, or "drag," and the roller or planker. The disc harrow breaks up the hard lumps into fine particles, the "drag" further pulverizes these lumps into a smooth seed bed, and the roller compacts the top soil, so that there is not too much space between the soil particles in the plowed surface. While the last named implement is not as commonly used as the other implements mentioned above, it has its merits, and will be found to be a paying proposition on most farm land, when preparing the seed bed for the various crops.

Besides requiring the seed bed to be mellow and firm, we also want our farm soils tilled to aid in destroying weeds, conserving moisture, preserving the texture of the soil, and the liberation of the plant food elements. Weeds are a great source of trouble on a great majority of our American farms, and if the crops are not cultivated, in many cases, the weeds will smother out the original crops, with the result that we would get a very meager crop. By cultivating, or shallow plowing, between the rows of the crops that are capable of being cultivated, the weeds can be held in check, and this gives the crop the benefit of the plant food. There are a few weeds that are especially difficult to kill out, such as quack grass and Canada thistle. However, these weeds can be eradicated, if the piece of land so infested with these weeds is put into some cultivated crop for a few years, and a determined effort is put forth to kill them out. By constant cultiva-

tion, and hoeing between the plants in the rows, a great deal of this trouble can be remedied.

Usually after a heavy rain, we find the soil hard and compact. If the soil is left in this condition, a great amount of the soil water will evaporate, which is a considerable loss to the crop, as the crop should have the advantage of all water in the soil possible. However, if we cultivate the soil between the rows of the crops that are what we call cultivated crops, we can stir up this upper crust of the soil, so that this evaporation is almost entirely eliminated.

Some soils, especially those containing a large percentage of clay, have a tendency to bake during a long, continued, dry, hot spell. This is harmful to the texture of the soil, causing it to be hard and lumpy. By stirring the soil occasionally, this condition can be eliminated to a large extent, and a loose texture maintained.

Finally, the cultivation of the soil also causes plant food to be liberated. By the admission of air into the soil, certain beneficial bacteria are enabled to break down, or decompose the plant food from an insoluble form to a soluble form, thereby producing more food for the plant to take up.

For those who are not very familiar with farming operations, the meaning of cultivated crops had better be fully explained. A cultivated crop is a crop that is planted in rows, so many inches, or feet apart, so as to allow a cultivator to go between these rows, during the growing season, to stir up the soil for the reasons mentioned above. Examples of such

crops are corn, potatoes, tobacco, and a garden, on a somewhat smaller scale than the first three mentioned crops. There are, however, a great number of farm crops that are not cultivated crops, such as wheat, barley, oats, timothy, clover and alfalfa. In a few sections of the country, alfalfa, the last named crop, is raised as a cultivated crop, but this condition only obtains in a small section, where artificial irrigation is practised.

The time of plowing varies in different sections of the country, as well as in the same section of the country, under varying conditions. We will present the advantages of both fall and spring plowing next, so that the underlying factors may be understood, then one can choose for himself which is the best time for his own particular circumstances.

Most farmers are exceedingly busy in the spring of the year, with such operations as seeding, hauling the manure out on the land, working up seed beds, etc., so that if a great deal of plowing is to be done in connection with these other pressing duties, they are quite liable to fall far behind in their spring work. During the fall, until it freezes, and especially after the crops have been harvested, the farmer finds it to his advantage to plow his land as much as possible, until it freezes so hard that he cannot plow any more. Of course, there are certain times that conditions are unfavorable for fall plowing, such as when the soil is either too wet, or too dry. But there is usually quite a number of days that he can fall plow to advantage, which means he does not have to plow this field

in the spring. When sod land is to be plowed, it can best be plowed in the fall, as this gives the sod a much longer period of time to decompose before planting time. Furthermore, fall plowing enables the soil to catch the winter rains and snows, thus preventing them from washing away. It also has a harmful effect upon certain crop pests that prey upon the crops and destroy them. Finally, it especially improves the tilth of heavy or lumpy soils, such as clay, for instance. By alternate freezing and thawing, these hard lumps are almost pulverized by spring. Thus we see that fall plowing has many very distinct advantages.

Often it is impossible to do very much fall plowing, for one reason or another, and, as a result the bulk of the plowing is done in the spring. When this is the case, the soil (especially if a heavy clay) is quite liable to have a poor texture, if there are the usual spring rains. However, in some cases, spring plowing is to be preferred to fall plowing. Often it is advisable to sow a green manure crop, such as rye, on a piece of ground, after the crop has been removed. It can then be left on the ground until spring, when the rye can then be turned under, thereby supplying organic matter to the soil. Also, many sandy soils give best results when left until the spring to be plowed, as often this type of soil is subject to blowing if plowed in the fall.

We have now quite a pretty fair comprehension as to the meaning of good tilth. However, it must not be concluded that if a soil has good tilth that it is necessarily a fertile soil.

Of course, good tilth is to be desired in a fertile soil, but a soil rich in fertility, or plant food, may seriously lack good tilth. By the same token, a soil possessing good tilth may be quite lacking in soil fertility. For instance, a sandy soil usually has good tilth, or we may say that it is easily worked up. But the chances are that this sandy soil is not very rich in soil fertility. Hence, we see that there is no direct correlation between the two factors.

FUNCTIONS OF SOIL WATER

There are several very important reasons why plants require water. We have already seen something about the activity of water as a carrier of plant food from the roots of the plant to the leaves, and also noted the fact that the water carries the manufactured plant food to the various parts of the plant from the leaves. The water performs other important functions in the plant as well. It is one of the forms of food that the plant uses in the process of growing. The constant evaporation that goes on from the leaf surface of the plant has a cooling effect upon the plant, thereby preventing it from succumbing to the intense heat of the hot summer temperature. The presence of water also prevents the plant from wilting.

We have noted in a previous chapter that crops are ordinarily very large consumers of water during the growing season. In one case, we noted that it took over one hundred and fifty barrels of water to make possible the pro-

duction of one bushel of matured corn. While not all crops are as severe on the moisture supply as corn, still, most of the farm crops use over one hundred barrels of water during a single season to produce one bushel of matured grain. From these few observations, it can be readily seen that the moisture supply of the soil is of prime importance.

We will now turn our attention to the supply of rainfall during the growing season. Rainfall is usually spoken of in inches. If we have one inch of rain during one storm, we can say that we have indeed had a heavy shower. When such an amount of rain falls in one single storm, its quantity can easily be appreciated by noting the condition of the roads. Ordinary roads will not be suited for automobile travel for about two days after such a copious rain fall, unless chains are used. In some of the "gumbo" soils in the west, a much longer period is needed for chains. From this we can get a fair idea of what "an inch of rain" signifies.

Unfortunately, we cannot regulate our rainfall. We must take it as it comes. Too often it comes at the wrong time, and too seldom at the opportune time. However, we must make the best of these conditions, unless we are located in an irrigation district, where the soil is moistened artificially. The rainfall is not uniform over the entire country. Some parts of the country receive, annually, thirty inches or more of rainfall. Such climates are termed humid climates. Sections where the average rainfall is over twenty inches, but less than thirty inches per year, are called sub-humid

climates. Still there are other sections of the country, such as in some of our western states, where considerably less than twenty inches fall in one year. These sections are known as dry or arid climates.

Splendid results would obtain if we could have our rains just at the time when they would do the most good. Owing to the fact that rain comes at irregular intervals, the farmer must conserve the moisture as best he can, by proper tillage operations, supplying sufficient humus to soak up the water, etc. After a heavy rain, the farmer usually gets out on the land as soon as it is dry enough to work, and breaks up the hard crust formed by the rain, and leaves a crumbly mass by means of his cultivating implements. This prevents the moisture from evaporating too rapidly.

Soil water may exist in the soil in three different forms. It may be present in the soil as hygroscopic water. This form is present in soil that is air-dried, and is of no special importance. It may also be present as gravitational water. This form is also known as free water, and is characterized by its tendency to run off the soil, or seep down through the soil due to the force of gravity. We see illustrations of this form when we get a hard rain. Not all of the water has time to be absorbed by the soil, and a great quantity runs off the high land into brooks and streams at the lower levels.

The third form of soil water is the one with which we are most concerned. This form is known as capillary water, and it is this form

of water from which the plant takes its moisture, and also through which it derives its plant food elements. Ordinarily, one would be led to the conclusion that the low pieces of land, which are wet the longest period of the year, should produce the greatest yields, due to the dependence of crops on the water supply. But it has just been stated that the plant does not use this free water for its supply, but rather the capillary moisture. Let us now examine this capillary moisture, as it is an exceedingly interesting process.

There is usually a water line in soils that is some distance below the surface of the soil. This water, existing in the free state, has a tendency to work upwards, at this particular point. Its movement upwards is not unlike the action of kerosene in the wick of a lamp. The water surrounds the fine soil particles, forming a thin film of moisture around the surface of these particles. The moisture does not stay in one place, but constantly moves over the surfaces of these soil particles to a drier point. The reason for this constant movement of film water is this: Near the surface of the soil, especially if the soil is a compact hard mass, and lacking cultivation, there is a constantly giving off of moisture, either through evaporation from the surface of the soil, or by giving up soil moisture to the little rootlets that we studied about in a previous chapter. As a result, the upper portion of the plowed area of the land is constantly drawing upon the moisture supply. The tendency of the capillary water is to constantly move to the drier sec-

tion, which is generally towards the top surface. As a result, the capillary moisture film of water, which surrounds each soil particle, keeps climbing up from one soil particle to another in an effort to reach the dry section. But as soon as it reaches the dry soil particles, it may either be absorbed by the rootlets of some plant, or, if cultivation is lacking, it will be evaporated off from the surface of the soil. Thus it will be seen that the plant can continue to grow for quite a long period of time despite the lack of rain, if there is a good supply of capillary moisture.

This capillary action of soil water, as has been stated, is the source from which all plants receive their water, which in turn carry a weak solution of some of the soil elements. It has been shown that what moisture is not taken up by the plants will evaporate from the surface of the soil if conditions are favorable for this action. However, man has devised a way by which he prevents a large part of this loss of moisture. Man has found that if he stirs the surface soil, thereby breaking up the soil particles so that these particles are too far apart for the capillary moisture to climb from one particle to another, this moisture will come up as far as the lower edge of the broken up surface, and remain there, not being able to climb to the very top, so that evaporation is thereby checked to a great extent. When the soil is thus stirred, we say that we have mulched the surface of the soil. This mulch, to state the matter in another way, is simply the top soil stirred up in such a manner that the soil par-

ticles are not as close together as they were, thereby greatly discouraging capillary action and evaporation of moisture.

As the capillary moisture is contained mostly on the surface of the soil particles, it can be seen that the smaller the particles are, the greater the amount of moisture which can be contained in one cubic foot. One can realize this perhaps more vividly, if he takes an apple, and cuts it up into four quarters. He can then realize that he has more surface of the apple exposed, when thus cut up, than he did before the apple was dissected. Consequently, a soil containing fine soil particles, such as clay, or even silt, has much more capillary moisture capacity than has a sandy soil, as the sandy soil particles are the largest in size, and the spaces between them too large to cause capillary action. This partially explains why a sandy soil will not withstand a dry spell as well as a clayey soil.

Another source of moisture supply in soils is the amount of organic matter contained in the soils. This has been mentioned before, but we will discuss it more in detail at this time. We have seen that the organic matter plowed under acts somewhat like a sponge, in that it retains the moisture in the plowed area to a certain extent. This aids the plant during the dry spells, as it furnishes the soil particles with moisture if the supply below is exhausted. It also aids in another way, by preventing too much of the water during a heavy rain from leaching down through the soil. Besides these advantages in regard to moisture, it also aids

in the tilth of the soil. A soil is always much easier to work when it contains a good supply of this decaying vegetable matter.

Soil water is appreciated in some of our dry-farming sections much more than it ordinarily is in the humid parts of the country. In the dry-farming sections, where the annual rainfall is less than twenty inches, every effort is put forth to conserve this moisture. It often becomes necessary to raise a crop on a piece of land every other year, rather than every year, as there would not be sufficient moisture to mature a crop every year. Hence, a farmer, under these conditions might put various crops in 160 acres of his farm one year, if he owned a 320-acre farm, and "summer fallow" the other 160 acres. This is under the supposition, of course, that every acre was under the plow. By "summer fallowing," we simply mean that the land is worked up so that a mulch will be placed on the surface of the soil, especially after a rain, so that the moisture will not escape. This shows us that the moisture supply is an extremely important issue and that the wise farmer, whether he lives in a dry climate or a wet climate, will do everything possible to conserve the moisture, as the success of his crops depends more upon this factor, year in and year out, than any other one thing.

NATURAL METHODS OF ENRICHING THE SOIL

There are two important and practical ways by which the soil may be enriched, naturally. These methods are the addition of green manure and barnyard manure. We will consider the green manure proposition first. A green manure crop is a crop that is raised for the express purpose of plowing it under when at a certain stage of growth. There are many such crops raised by the farmers of this country annually, for the purpose of improving the texture of their farm land. Crops such as rye, or clover, make excellent green manure crops. They should be turned under, or plowed under, when still green, but not when they have grown too rank. If turned under when they are tall and coarse, this serves as a check for the rise of the capillary moisture, and the following crop is liable to dry out, due to the interception of the capillary moisture from below.

Leguminous crops, or crops that manufacture nitrogen in small nodules on their roots, by means of bacteria, are the best green manure crops to raise, because they not only improve the texture of the soil by their decaying vegetative matter, but also add considerable nitrogen to the soil as well, because of the activities of the bacteria present in the roots of such plants. As nitrogen is an important element in the soil, this factor is being considered seriously by many farmers to-day, in their efforts to increase the nitrogen supply of their soils.

More important in the upkeep of the soil fertility of the American farm land, however, is the problem of barnyard manure. We American farmers have much to learn yet in the proper handling of the farm manure from our European cousins. As a whole, the American farmers do not appreciate the fact that the liquid portion of the manure is the richest part of the fertility, and anyone familiar with farm conditions can testify to the fact that it is an all too common practice in this country of dumping the manure daily, throughout the year, in a heap outside the barn door, where the liquid is allowed to run off or evaporate, so that when what is left is hauled out on the land, more than half of the fertilizing value of the manure has been lost, and the only advantage of the remains lies in its rich supply of organic matter, rather than in the maximum suppy of fertilizer.

There are, in general, two ways by which this manure can be handled properly by the farmer, so that this loss of liquid material can be largely eliminated. One way is the use of the manure pit, that has a concrete base and sides, so that none of the liquid can leach away. This pit should also be provided with a roof, to keep out excessive rains. Many farmers have devised the system of having an overhead track run from the barn to this manure pit, or shed, and have the manure transported in a carrier which travels on this track. The load can be dumped then, when it reaches the shed, and returned to the barn. This method allows the farmer to save practically all of his

fertility during the winter months, and then he can haul this material out on his land in the spring, and spread it by means of the widely used manure spreader.

There is another method that is also used by many farmers in saving this fertilizer, and that is the process of hauling it out every day during the winter, directly from the barn. This is more tedious, as there are many days during the winter when it is almost impossible to get out on the land, due to snow storms, etc. Where the land is hilly, it is not advisable to spread manure in the winter time, as a considerable portion of the liquid material will run off sloping land, and be lost. However, this objection can be overcome by waiting until spring to spread the manure on the hilly portions and fertilizing all the level land during the winter months. This method of hauling saves rehandling in the spring. This fact is appreciated by many farmers, who always have about twice as much to do as they can accomplish during the spring months. There is also a slight loss of beneficial bacteria incurred by this method, but not enough to offset any of its advantages. On the whole, this method has been worked out very satisfactorily by quite a large number of American farmers.

There is quite a direct correlation between the kind of feed given to farm animals, and the value of the manure. Animals that are fed feeds low in protein produce a manure that is also low in nitrogen. This is a factor worthy of attention. Inasmuch as barnyard manure,

even when handled with the utmost efficiency, is not a complete or perfect fertilizer, it is important that the farmer bring up to as high a standard as possible the manure which he applies on his land. This he can do by feeding his animals efficient rations having a sufficient quantity of protein in the feeds, and when exercising care in preventing losses through leaching, as has just been described.

There is another quite common method of handling manure on the farm, and that is the practice of hauling it out to the fields in piles. This method, while superior to the old method of leaving it in the barnyard all winter, has its faults, however. The field in which the manure is piled will be uneven the next year, as the liquid will leach to quite an extent in the particular spots where the piles are located. This method also involves a rehandling in the spring, although the time consumed in this case is not as great as when it has to be hauled from the barnyard. One can easily pick out fields, during the summer time, where this method has been employed. The spots where the heaps of manure had been piled produce much more abundant, rank crops than the surrounding area, thereby causing difficulty in harvesting.

It is certainly interesting to observe the methods of some of the European countries in their fertility problems. In these countries, especially in France, the manure is piled on solid foundations, to prevent leaching, and many other materials are constantly added to the pile during the year, such as leaves, stub-

ble, straw, and even discarded wearing apparel, and then this mixture is applied to the land in the spring. The time will soon come in this country, with land not so plentiful, when we shall be forced to stop this huge waste of fertility, that is leaching away from the farmer every day, and to substitute a more careful and more efficient method.

COMMERCIAL FERTILIZERS

We have seen in the previous chapter that barnyard manure, even when given the most intelligent care, does not return to the soil all of the plant food removed by the crops. Consequently, it is not difficult to conclude that when this manure is improperly handled, an even greater loss is sustained by the farmer. In order that this land may be kept perpetually productive, this barnyard manure must be supplemented by some other form of fertilizer. This brings us to the discussion of "commercial" fertilizers.

The use of commercial fertilizers is not universal, by any means. These fertilizers find their greatest use on the lands that have been farmed the longest in this country. Many of the states in the eastern part of our country use commercial fertilizers to a large extent. While it is true that some of these fertilizers are used in the western states, their application is not nearly as common in this section as in the East. For instance, a western farmer might apply two or three hundred pounds of the fer-

tilizer per acre and get splendid results, while it is quite common for a potato grower in the State of Maine to apply a ton to the acre. There is a certain prejudice against these fertilizers among some farmers, but it may be said that the proper use of commercial fertilizers is a paying proposition. Some farmers believe that after a farm has once had commercial fertilizer applied to it, the land "burns out," and that in order to get crops thereafter, he must continually resort to this form of fertilizer. This is a mistaken notion, however, because when these fertilizers are used intelligently they do not "burn out" the land, nor make it "lazy." One good use of these fertilizers was described in a previous chapter under the test plot method. When a land is deficient in nitrogen, for instance, is it not a far better practice to supply that lacking nitrogen in the form of some kind of fertilizer, than to try to farm the land with its lack of nitrogen? Anyone can see the common sense of the argument who is willing to reason from facts.

We have discussed briefly, in the chapter on test plots something about commercial fertilizers, but we will now endeavor to study more thoroughly this phase of soil improvement. We have already learned that nitrogen, phosphorus and potassium, otherwise known as potash, are the chief elements which the plants draw from the soil. Consequently, these three elements are the ones that must be replenished continuously. Let us take each of these elements separately, and see how each one can be handled in the most successful manner.

Nitrogen is restored to the soil, we have learned, by means of raising leguminous crops, and this is especially true when these crops are turned under. Also, there is a good supply of nitrogen in the barnyard manure when applied to the land. But often, as has just been stated, over half of this is lost through careless handling of the manure, and, furthermore, there usually is only enough manure on the ordinary farm to cover but a small area of the farm each year. Therefore, if we are to obtain the highest production from our land, we must plan to add this nitrogen in a commercial form.

Nitrate of soda is one of the most popular forms of commercial nitrogen fertilizer. This form of nitrogen is very readily available as a plant food, and because of this fact, it is usually applied at different intervals, rather than all at once, because it readily leaches out of the soil. This fertilizer is usually applied at the rate of 200 to 300 pounds per acre.

Ammonium sulphate, cotton seed meal and dried blood are often used as a source of nitrogen, especially the ammonium sulphate. These forms of nitrogen are not as easily available as the nitrate of soda; therefore, results will not be noticed as quickly with these forms as with the soda compound.

Acid phosphate is the most readily available form of the phosphorus fertilizer. This is usually applied on the land at the rate of from 200 to 500 pounds to the acre. Another form of phosphate is the rock phosphate, which is merely ground up rock containing a high per-

centage of phosphorus. This is very slowly available, and results from this source cannot be noticed for a year or two after it has been applied. However, it is much cheaper in cost, and many farmers follow the practice of mixing some of this with every load of manure that is spread on the land, thereby making the spreading of this form a simple matter. Steamed bone meal, finely ground up, offers another source of commercial phosphorus. This is a by-product from the large packing plants and after the bones are steamed at these plants, they are ground up, and sold out, especially to truck gardeners, for phosphorus fertilizer. This form is usually applied at the rate of 200 to 300 pounds per acre.

Potash fertilizers have in the past been largely supplied from the Stassfurt mines of Germany. This is a large potash salt deposit, and these mines alone have supplied a good share of the world's potash in the past. The chief combinations of this fertilizer in commercial form are sulphate of potash, muriate of potash and kainit. These are various forms of Stassfurt potash salts, and are all soluble in water. Unleached wood ashes also contain a fair amount of potash, especially hardwood ashes burned at a comparatively low heat. If these ashes have been exposed to the rains, however, they are of little value as fertilizers.

In our previous study of the test plots (see page 23) we found that we could determine by that method just what a certain piece of land needed by way of fertilizers. Often a farmer finds that he gets best reults by applying what

is known as mixed fertilizers. A mixed fertilizer is a combination of the three fertilizers that we have been dscussing, namely, nitrogen, phosphorus and potassium. In such a case, there is no serious lack in the soil of just one element, but the conclusion is that all three are more or less needed.

Another element that is sometimes needed by soils is that known as calcium, or lime. While lime is regarded chiefly as a soil neutralizer, it is a fact that it is often used by plants as food. Alfalfa and tobacco are good examples of heavy lime feeders. When it is found that lime is needed, this can be applied the same as the other fertilizers, about a ton to three tons to the acre. We will take this matter of lime more in detail in the following chapter.

SOIL ACIDITY

It seems to be a common experience of many farmers that their land fails to grow certain crops as well as in previous years. Of course, there may be various reasons for this state of affairs, but one of the most frequent and important, in the humid climates, at least, is the absence of lime in the soil. Crops like alfalfa and clover, for instance, are often failures in humid climates, for no other reason than a lack of lime. These particular crops do not succeed because the bacteria (which we have mentioned before as working in the roots of these plants and converting the nitrogen of the soil air into nitrogen that the plant can utilize) cannot work in a soil that is not

up to the standard in lime. We term such a soil deficient in lime, an acid, or a *sour soil.*

There is only one practical way by which this sour, or acid, soil can be sweetened, and that is by applying lime in some form. But this liming aids in other ways, incidentally, besides neutralizing the acidity of the soil. It adds plant food in the form of lime, which is used quite heavily by certain plants. Strange to say, other plant foods existing in the soil are made more available by the addition of lime. Lime also improves the structure of the soil, thus causing the soil to be more easily worked.

It is not an uncommon experience for a farmer to try to get a start in raising alfalfa, which is without doubt one of the best forage crops that we have. He may choose his best piece of ground, and may take ever so many other precautions, but if the land is acid, he will have poor success, because, as stated before, the bacteria in the soil, so essential to this crop, cannot exist in an acid soil. The only way in which he can succeed in raising this crop, providing he has a well drained piece of land, and has the bacteria introduced into the soil, if not already present, is to apply lime on this land. If this is done, the chances are very much in his favor in securing a good stand of alfalfa.

The next problem that confronts us is the manner of determining the acidity of our soils. How can we tell if our land is acid or not? There are various methods of reaching a conclusion in this matter. The old method consisted of using a small strip of blue litmus pa-

per, and bring this in contact with some moist soil. If the blue color of the litmus paper changed to a reddish hue, then we would know that the soil was acid. But a weak acid soil would change the color of this blue litmus paper just as much as a strong acid soil would. Hence, by this method, the farmer did not know how much lime should be applied to correct the acidity. Within the last few years, however, the Truog Acidity Test has become available, and it is now a matter of but about five minutes' time to determine accurately not only how acid the soil is, but a chart is also provided, showing just how many tons of lime should be applied to the acre for that particular field. Most state experiment stations have this test, or a similar one, and any farmer can either send a small sample of his soil to his state experiment station, or agricultural college, and they will run the test off for him. Possibly, the county agricultural agent has one of these, and as he is in the county for such purposes every farmer who is anxious to determine the acidity of his soils should take the proper steps to obtain a reliable answer to his problem.

The luxurious growth of certain weeds is almost a sure sign of acid soils. Such weeds as the common plantain, sheep sorrel, corn spurry and horsetail all thrive best on these acid soils.

There are many different forms of lime that can be applied to the soil to correct the acidity. Ground limestone, burnt lime, marl, marble dust, pulverized corals and shells are different forms of lime that may be used. However, the

first two are the forms most commonly used. Ground limestone is a reliable form of lime to use, although not quite as quick in its response, as the burnt lime. In many communities there are large deposits of lime rock that are capable of being crushed and ground finely enough for agricultural purposes. When this can be secured, it will probably be the cheapest source available, unless the distance of hauling is too great. A farmer might plan to haul this lime during the summer or fall, but as he generally will not have the time for such extra work, he may safely leave it for the more leisure winter days, without a serious loss of results.

Another form of agricultural lime is lump, or burnt lime, already mentioned. This is made by heating the limestone to an intense heat, in specially constructed kilns, thus driving off the impurities, and leaving the common lump lime. When this lime in the lump form is finely ground, it is ready to put on the land. There are many companies that make a business of preparing this lime, and selling it in carload lots to groups of farmers.

In regard to the time of applying the lime on the land, it might be said that the sooner it is applied, the better. If it can be put on during the fall, after a crop has been harvested, and allowed to stay in the soil over winter, much better results will be obtained than putting it on the land just before the crop is put in, in the spring. Whenever lime is put on, fall or spring, it should be thoroughly worked into the soil, rather than allowed to remain on top.

SOIL FERTILITY DETERMINES YIELD

The term, "fertile soil," has been used in this little booklet with reference to the amount of plant food in the soil. However, under practical conditions, we find that sometimes a soil may have a good supply of the needed plant food elements, but nevertheless fail to yield a satisfactory crop. That is to say, a soil, to be productive, requires not only sufficient plant food in available form, but certain other conditions, such as good seed to start with, light, a warm temperature, protection from the various harmful agencies, such as insects and diseases, and plenty of humus, or organic matter in the soil. Thus to get the maximum yields of our farm crops, we must understand that while plant food is absolutely essential, it is not the only factor to be considered if we are to get best results.

Just what is the importance of good seed? Suppose we plant an acre of corn with seed that has poor germination. Let us say that the germination of this corn is 75 per cent, or that 75 kernels out of every 100 kernels sprout. The best that we can do under these circumstances, providing we have other conditions ideal, is to get a 75 per cent yield. This is a costly affair to the farmer, as 25 per cent of his acre of land is wasted, and weeds will take possession of the wasted land, if the land is not closely cultivated. Of course, the farmer can go to the bother of replanting the missing kernels, but this is also a drain upon the farm-

er's time during this busy period. It is a fact that a great many farmers do not test out the germination of their seeds before planting their seed, often with disastrous results. In fact, often a farmer has to replant an entire crop because of the failure of his seed to germinate.

The quality of the seed also is a matter worthy of consideration. Is it worth while to pay a little more for seed of good quality, such as corn, for instance, or shall the farmer go to the local elevator and purchase a lot of ordinary crib corn for planting purposes? To be sure, he can get crib corn for just about market price, whereas he would have to pay two or three dollars a bushel for good seed corn. But he can make many times the difference in his yield of corn by paying a little more for good quality seed corn, that has been selected for high yield, and that has been cured properly, than he can by trusting to the outcome of his cheaper corn. The same problem of proper seed applies to other crops; I have only taken corn as an example to illustrate the situation for all crops.

We have seen in a previous chapter that light is essential for the manufacture of plant food by the chlorophyll present in the leaves of the plant. This is a factor generally beyond the control of the farmer, as he has to take the light as it is given to him by the sun. But the fact remains that crops have to have a certain amount of sunlight to make this plant food, although some plants demand much more sunlight than others. In fact, some plants require very little sunlight to mature. This is

illustrated in the State of Conneticut, where tobacco is raised largely in the shade, under canvas tops. A very excellent quality of tobacco is raised in this state by having the tobacco land covered most of the season with large canvas tops, so that the shade can be artificially controlled.

Why do not farm crops grow during the winter? This is apparently a foolish question, but it brings out the importance of the need of a warm temperature for plant production. Some crops will grow in comparatively cool weather, while others need a warm climate to grow to best advantage. We always plant our oats a few weeks earlier than we do our corn, because we have found that oats will grow at a lower temperature than corn will.

Another factor that is gowing more important each year in the production of our farm crops, is the matter of insects and pests. Nearly every crop raised at the present time has some natural enemy, either an insect or a plant disease. Most of us can recall the struggle of our potato plants during the growing season, as a good illustration of this fact. We know that the ever present Colorado Potato Beetle, commonly known as the "potato bug," will eat up a good part of the foliage of the potato plant, if it is not given a stomach poison of some such material as Paris Green, or arsenate of lead, sprayed on the foliage. Then the matter of diseases demands attention. We can again refer to the potato plant in regard to such diseases. Either early blight, or late blight is a common enemy to the foliage of

these plants, especially when the season is moist during the time that these diseases are prevalent. As a matter of fact, every crop that the farmer raises, has to fight a struggle against these insidious enemies. Many farmers are aware of the chinch bug, boll weevil, grasshoppers, cutworms, as good examples of insect pests, and of rust, smut and other fungus diseases that play havoc with the farm crops during the growing season.

We have discussed the benefits of humus, or organic matter, in the soils. We have learned that this material is simply decaying vegetable matter in the soil. No soil is very productive that lacks any appreciable amount of this material, as this humus is a great factor in improving the tilth of the soil, and its fertility. When a field is sown to certain cultivated crops, and these crops are removed from the land, and nothing is put back into the soil, then we have a soil soon deficient in organic matter. The soil becomes hard and difficult to work. This can be remedied by a method known as "rotation of crops," whereby different crops are raised on the same field in successive years, and one of these crops should be a hay crop, such as clover, for instance. The clover can be raised on the piece for two or three years, and finally plowed under, thus providing a good supply of vegetation to supply this organic matter, and incidentally furnishing considerable nitrogen.

Besides the factors already mentioned determining the yields of farm crops, we might mention a few other requisites that are essential

to a fertile soil, if maximum yields are to be expected. We must have a sufficient amount of moisture in the soil, because we have seen how the plant takes its food in the form of a weak solution. If this moisture is not present in the soil, then, no matter how much plant food is present in the soil, it will be of little value to the plant, because it has to depend upon moisture to supply its food in a form in which it can utilize it. In some of the dry sections of the country, this moisture is supplied by means of irrigation, where certain water paths are provided, running down through the field at regular intervals. This furnishes the moisture necessary to dissolve the elements in the soil, so that the small rootlets of the plants can absorb the moisture containing the plant food. Many of our best crops are raised in these irrigated districts. Sometimes, however, we find that we have too much moisture in the soil. This is especially true in low places. It then becomes necessary to drain the soil of this excess moisture, so that the spaces between the soil grains are not clogged with water, and that sufficient air may be present. It has been estimated that considerably over one-fifth of the land in this country, capable of being cultivated, needs drainage, and that in the near future all this land will be drained, to supply the ever-increasing demand of farming-land.

If the spaces between the soil particles are filled with water, it is obvious that air cannot be present in the soil. Strange as it may seem, a certain amount of air is essential in the soil,

because the roots of the plants will not grow if they cannot obtain air. Also, it is a common expression amongst soil experts, to say that crops will not grow when they have "wet feet." This means that the roots of plants will not go down into the water for their plant food, because they would be unable to breathe, if they did. The presence of air also favors the development of beneficial soil organisms and is an aid to certain valuable chemical changes which are continually taking place in the soil.

From what has been said, it is evident that there are several other factors determining the yielding ability of a soil, besides the mere amount of plant food contained in it. Not that it is the desire of the writer to lessen the importance of the presence of available plant food in the soil. This matter is all important. But it is not the only factor to be borne in mind, if we are to get the most from our soil. We must also look to such matters as proper tilth, good seed, favorable temperature, protection from natural enemies, and bear in mind the importance of replenishing the soil constantly with a sufficient amount of organic matter. When we take these precautions, we will have little difficulty in securing excellent results for our efforts.

BENEFITS FROM SOIL ORGANISMS

Soil organisms, and the benefits derived from these minute organisms, form a subject with which few farmers are familiar. Of these various soil organisms, bacteria are without doubt the most numerous, and also the most important. We do not ordinarily appreciate the great quantity of these bacteria that are present in the soil, neither do we begin to realize the immense number found in just a thimble-full of ordinary soil. It is no mis-statement of facts when we say that an ordinary thimble-full of soil contains about one billion of these micro-organisms. (A "micro-organism" is an organism which is too small to be seen by the naked eye, becoming visible under a powerful microscope.) This will serve to give us some idea of their number as well as their importance. There are three kinds of bacteria that we will especially emphasize, namely, those that cause decomposition, those which convert nitrogen from the air, and those which convert nitrogen from material already in the soil.

If we stop to ponder for a moment, we will have to admit that there is some agency always at work decomposing material things in this world. For instance, if we leave rubbish exposed to the weather for any length of time, and note the condition of the rubbish at some later date, we find that it is not in the same physical condition as it was when we first deposited it. It has undergone some decomposition. In fact, this decaying process is always

at work, either on top of the soil, or in the soil. This process takes place more rapidly in the soil, however, than on top of the soil, due to the fact, that these decomposing organisms are far more numerous within the soil than elsewhere. When we add any kind of material to the soil, and then turn this material under, so that it is thoroughly incorporated in the soil, these bacteria at once begin to break up the material into some of its original elements. If such a decaying process were not possible, we could easily see that the world would be littered up with an immense amount of trash from past products.

When the farmer turns under, by means of the plow, the various materials that we have discussed in these pages, these bacteria immediately commence to decompose this material, so that in a reasonable length of time, it is broken up into its several original elements, and these elements are then ready to be taken up by some other plant, and begin their nourishing function anew. Thus we see that there is a continual rotation of these elements. We can change the forms of these elements in various ways, but we can never destroy them, they are ever present in some form to be used again and again.

The story of the bacteria, which live in small nodules on the roots of leguminous plants, is intensely interesting to anyone, and particularly so to the farmer who is in the habit of raising any great quantity of such crops. Anyone can see these nodules, or small bunches on the roots of such leguminous plants by pulling up

a clover or an alfalfa plant. These nodules serve as small houses in which these bacteria that convert the nitrogen of the air into nitrogen for the plant, live. When the soil is not too acid, these bacteria enter the roots of these plants, in great numbers, and have the peculiar ability of taking the nitrogen from the air—the air enclosed between the particles of the soil—and changing it so that the plant can use this nitrogen for growth. In return, the bacteria suck a small part of the plant juices from the plant, but not in a sufficient amount to cause any check in the growth of the plant. When the crop has been cut, or harvested, and the season is too far along to make any more real growth, these bacteria then leave the roots of these plants and return to the soil.

In soils that are quite acid, these bacteria, for some reason that has not yet been determined, cannot thrive, and we must add lime to make it possible for them to work. If we wish to get a crop of alfalfa started, and the particular kind of bacteria that work on alfalfa roots are not present, what then? Well, we could do one of two things. We could either go to a field that had already raised alfalfa on it, and take off a few bushels of the soil, and haul it over to the field that was to be sown to alfalfa. This soil from the field that already had raised alfalfa would contain a sufficient number of these bacteria to give the new alfalfa a good start. But this method is sometimes a very laborious job. A much simpler method is for the farmer to send to his Agricultural College, and ask them to send him a bottle of

bacteria "culture," that contains countless billions of these living bacteria. By sprinkling this liquid culture on the alfalfa seed just before sowing it, he can very easily inoculate his soil; he can buy enough from this source for twenty-five cents to supply one acre of soil. There is still another form of these helpful bacteria that we have not as yet discussed, and that is the nitrifying bacteria, so called. These bacteria are unlike the bacteria just discussed, in that they do not add any nitrogen to the soil by taking it from the air, but simply change insoluble forms of nitrogen already present in the soil, to soluble forms of nitrogen which the plant can use. Most of this insoluble nitrogen is found in the organic matter that we have learned about. Hence, if there is not a sufficient supply of organic matter in the soil, there will be a shortage of this all important element, nitrogen.

There are many different kinds of bacteria found in soil, and most of these are beneficial to the crops. There are a few kinds, however, which are really harmful to crop production, in that they tend to waste some of the elements in the soil that should go to nourish the crops. These bacteria, however, thrive best when there is only a limited amount of air in the soil. The farmer can largely eliminate these harmful bacteria from his soil by aerating his soil and by various methods of cultivation, so that a liberal supply of air is always present in the soil. When this condition obtains, these harmful bacteria will have little opportunity for their destructive work.

CROP ROTATION AND SOIL FERTILITY

There is a close relationship between the rotation of crops, and soil fertility. By rotation of crops, we simply mean that for any given field on a farm, a different crop is raised each year, instead of raising the same crop on the same piece, year in and year out. This practice of rotating the crops each year on the farm is not a new system, nor can it be said that it is a comparatively old idea. In fact, many of our forefathers used to plant wheat on the same piece of land, year after year, until the crops dropped to such a low yielding stage, that it was no longer profitable to raise wheat on these lands. It is a generally accepted idea now that rotation of crops is the only sane method for permanent agriculture. We have already noted that different plants take varying amounts of plant food from the soil in one season. Let us take a specific instance to make this a bit clearer. Suppose that we grow corn on a piece of ground for five years in succession. What is the result? Is the fifth year's crop as large as the first year's crop? No, ordinarily, we would find quite a difference in the two yields. Then why is the last crop so much below the first one in yield? Corn is a heavy feeder of nitrogen, the ordinary corn crop on one acre, in one season, removing about 95 pounds of nitrogen. By raising corn in succession for five years, we find that we are drawing unusually heavily on the nitrogen supply, with the result that the amount

of available nitrogen present in the soil becomes the limiting factor. If there is only about half enough nitrogen in this piece of land the fifth year to produce a normal corn crop, then, as stated in an earlier chapter, we will get but half a corn crop, the yield being determined by the limiting factor, which in this case is nitrogen.

But what happens if we plant different crops each succeeding year? We will find that we get about a normal crop in each case, as the next crop, planted after corn, is selected because it is not such a heavy feeder on nitrogen, but uses more than a normal supply of either phosphorus or potash. One very common rotation in the Middle West is corn one year, oats one year, and clover two or more years, the clover being seeded with the oats the second year. This is done because the clover does not make any appreciable growth the first year, so farmers always sow this with a grain crop the year before they plan to use the clover crop. There are different rotations for practically every part of the country, so that no hard and fast rule can be laid down as to the best rotation to follow. The climate, nature of the crops raised, and various other factors all enter into the matter of selecting the best rotation for any particular locality.

There is another decided advantage in rotating crops besides those already mentioned, and this is the control of insect pests and diseases. By changing the land every year for each crop, the insects and especially the diseases are more easily controlled. Let us take the potato

again as a crop to illustrate the point. Most of us are quite familiar with the potato disease known as potato scab. This is a disease that attacks the skin of the potato, causing a rough appearance of the skin, and lowering the value of the potato materially. This is a fungus disease, and, we might say, "lives" in the ground over winter, and it is usually spread by planting potatoes that are affected with scab. If we raise one crop of potatoes on a certain piece of land one year, and the resulting potatoes are "scabby," we should not raise another crop of potatoes on this same piece for about four years afterwards, if we wish to eradicate the disease, as the next crop of potatoes, if planted on this land the following year, will acquire this scab from the ground, whether we plant potatoes free from scab, or not. Hence, we can see that rotation of crops helps in more ways than one to produce better crops.

It is a well-known fact among farmers that one of the most effective ways of killing out weeds, is to keep the field in cultivated crops for a few years. By rotating the crops in a certain field that is unusually infested with some noxious weed, such as quack grass, the weeds can soon be eradicated, if an earnest effort is put forth, not only with the cultivators, but by hoeing between the plants in the same row. If, however, a forage crop, or a crop that is not capable of being cultivated, is allowed to grow on a weedy piece for a number of years, then the weeds are liable to finally take possession of the field, unless an unusually vigorous stand of the forage crop is maintained.

CONCLUSIONS

There is probably no more fascinating study for a great number of people than the study of the soil. In these pages, I have tried to set forth the fundamental principles governing the nature of the soil, and some of the methods that have been found to be both practical and profitable by the men who have specialized in soil work. True, there are many things that we have yet to learn about the workings of the soil, but it is interesting to know what has already been found out, and to pass the word along. This is what I have attempted to do in these pages. The very nature of the various types of soils makes it imperative to work different soils in a different manner. For instance, the owner of a sandy farm would not only plant different crops than the owner of a clayey farm, but he would also work his acres differently—as in the various operations performed during the year, such as time of plowing, depth of plowing, methods of cultivating, etc.

To understand how plants use the soil as a means of growth, what the soil is composed of, how various micro-organisms aid in the decomposition of the soil, etc., is interesting as well as profitable information. Those who are especially interested in the nature of soils for some particular crop, I would advise to write to the nearest agricultural college and ask that their names be placed on the regular mailing

list for such information. There is probably no bulletin information available on all types of soils and their relation to particular crops, outside of this little booklet, and a few cloth-bound books of a much higher price.

In conclusion, I hope that the knowledge set forth in these pages will prove helpful to all those who are willing to follow the policies laid down, as this information comprises the accumulated results of extensive experimental and practical work.

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